Applying Multi-Scale, Multi-Physics (MSMP) Predictive Modeling Methods to Nuclear Reactor Applications

Presented at

Advanced Simulations Workshop at LLNL

by

Vlad Georgevich

Thursday, December 15, 2005

This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48

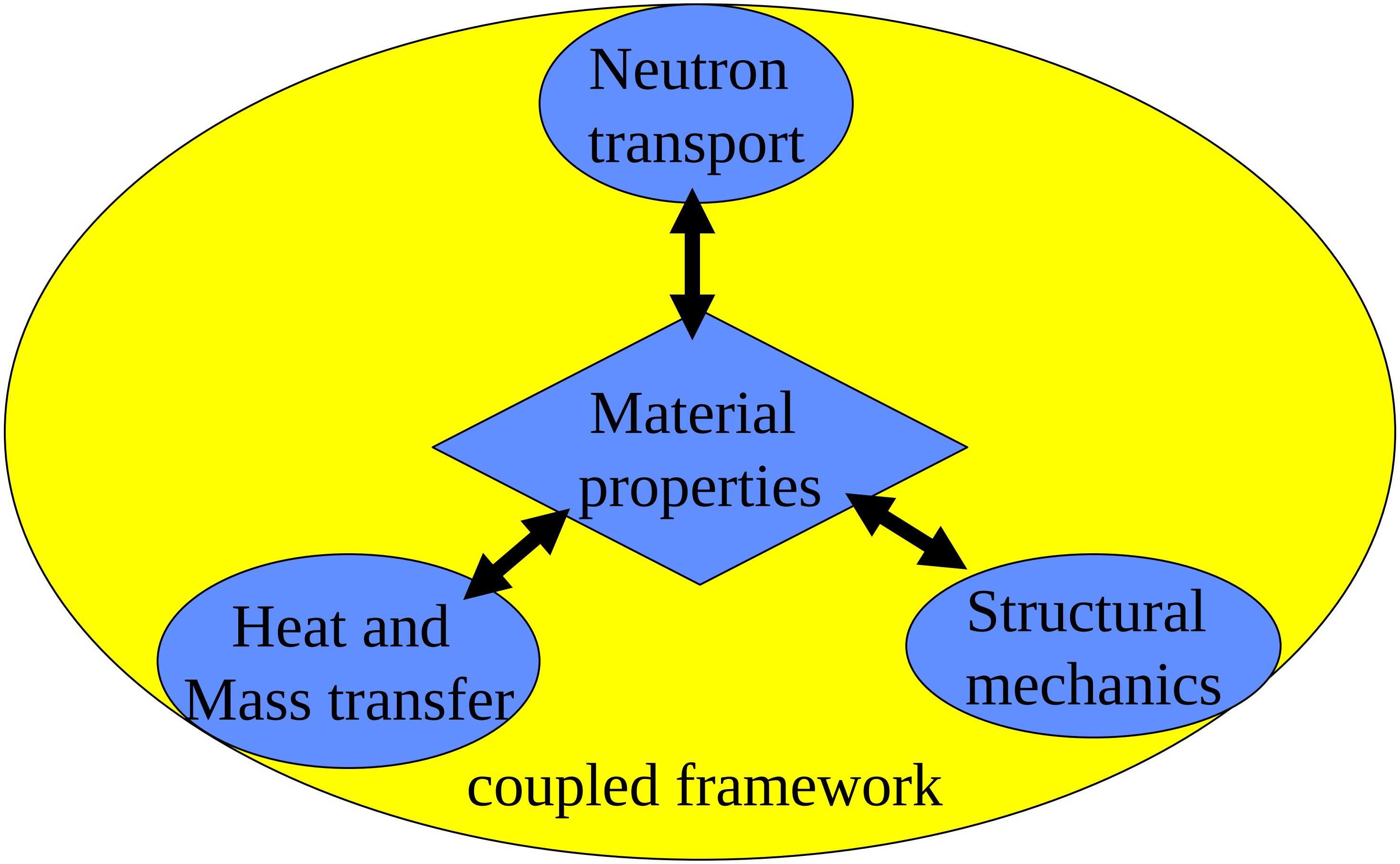
Outline

- Background MSMP problems
- Example of a MSMP reactor problem
- Example of a MSMP HE cook-off problem (successfully modeled)
- Summary

For two or more physical processes that have

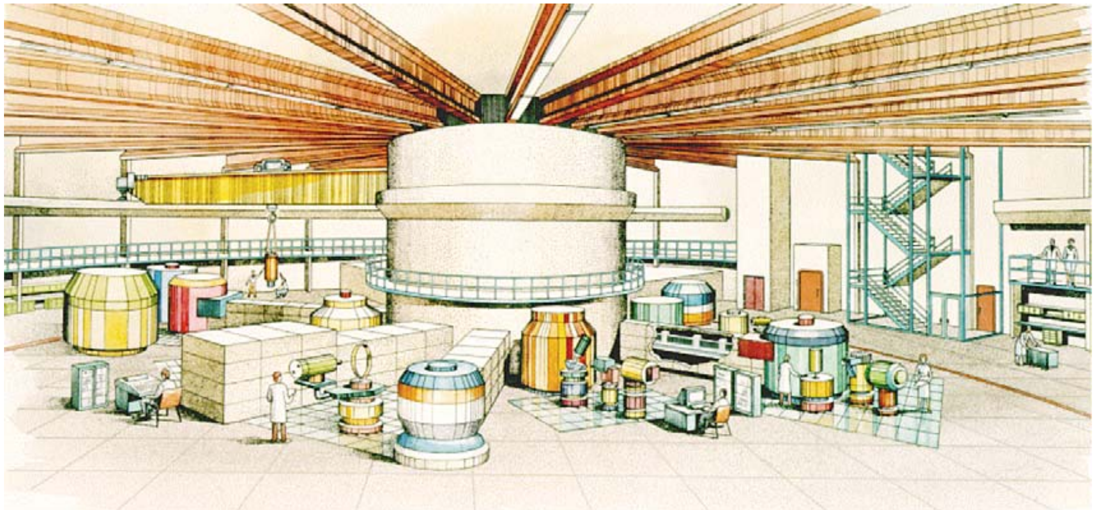
- similar time scales, multi-physics modeling is needed
  - Thermal shock: heat transfer drives a rapid change in density which drives stress fields
  - Shock initiated detonation: impact from an object initiates a shock that triggers chemical reactions, that transitions into a detonation
- changing controlling physics, multi-scale multi-physics modeling becomes important
  - HE cook-off : conduction heat transfer -> melting -> volumetric expansion -> chemical reactions -> phase change, -> material failure ….
  - Some reactor problems

Background: Three basic physical processes influence reactor performance



- **How tightly coupled should the platform be?**
  - **Depends on the controlling physics**

MSMP Reactor Example:
Flow Blockage of Advanced Neutron Source Reactor Core



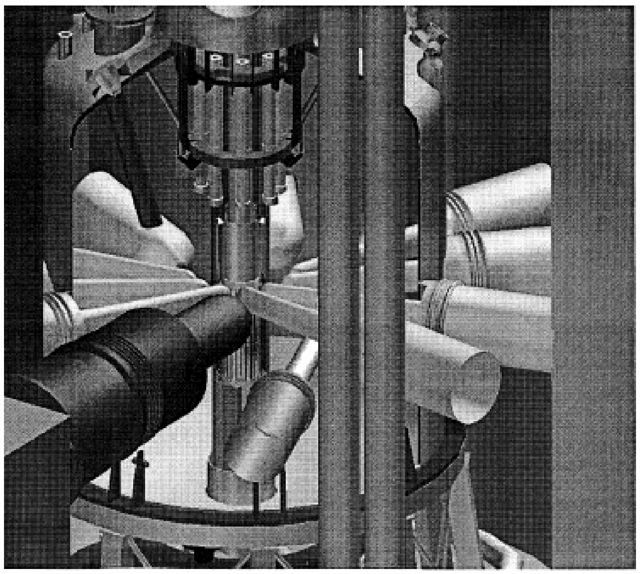
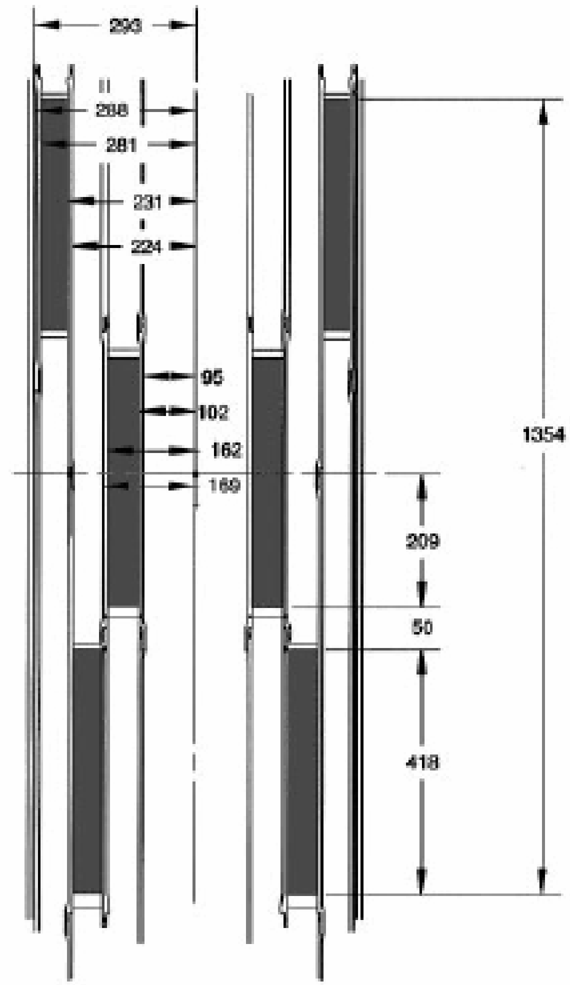


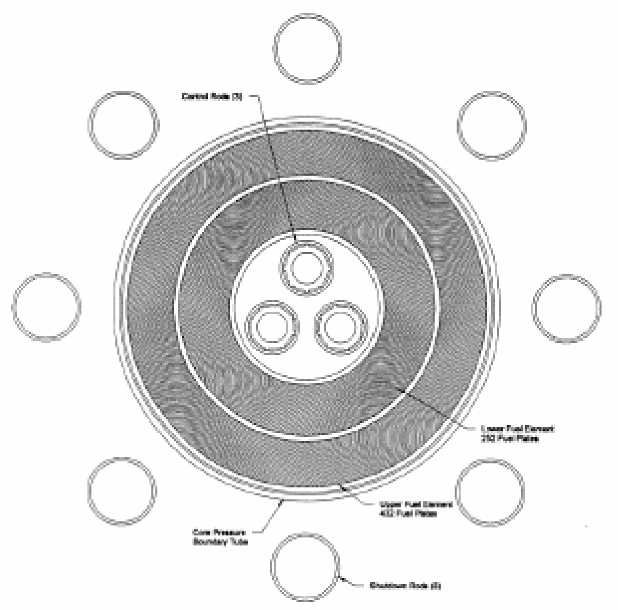
Fig. 4. ANS reactor assembly.

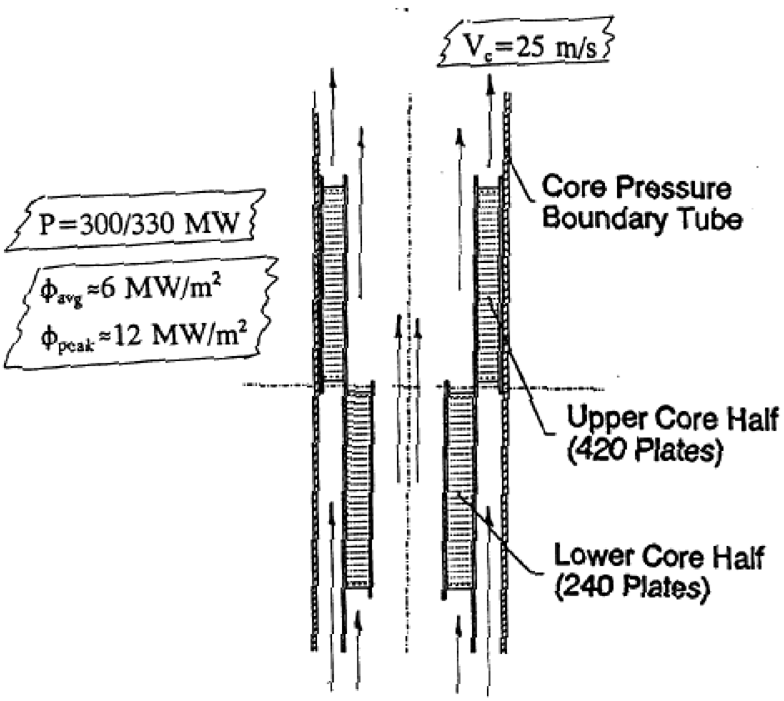


MSMP Reactor Example: Advance Neutron Source Reactor Core

- **Total size ~**
  - **100 kg of Aluminum**
  - **100 kg of U_3Si_2 dispersed in an Aluminum matrix**

- **Core**
  - **fuel plates that were ~1.25 mm thick**
  - **flow channel that was ~1.25 mm wide**





MSMP Reactor Example: Important physics and effects

- Important physics
  - Neutron transport, heat and mass transport, structural mechanics, material properties
- Effects of flow blockage
  - The flow field in the vortex behind the flow blockage reduces heat transfer
  - The boiling and two phase flow effects could be initiated
  - Loss of structural integrity of the fuel plate due to melting
  - Flow of molten cladding& fuel with coolant
  - Pressurization due to phase change
  - Propagation of the flow blockage, progressive melting of core, how it affects adjacent channels and fuel plates
  - The effect of aluminum water reaction (17 MJ / kg of Al)
  - The effect of steam explosion / chemical explosion on structural components.
  - Formation of missiles that would breach the confinement

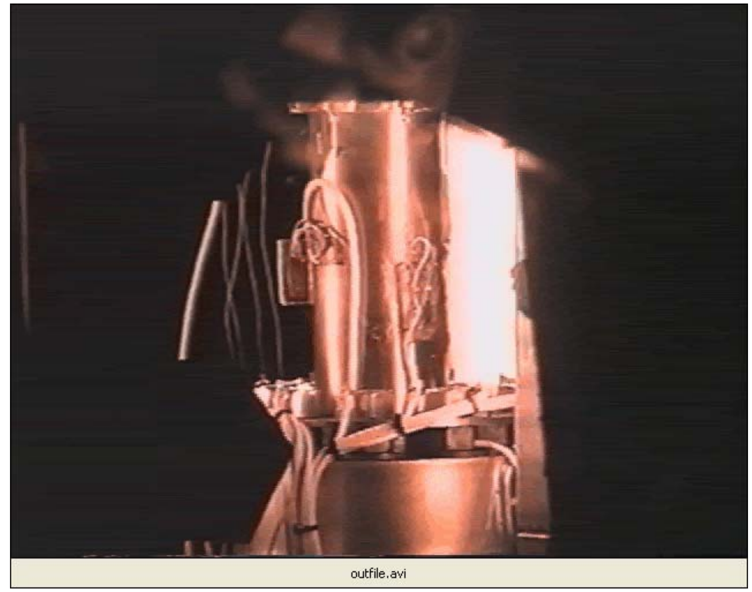
Time

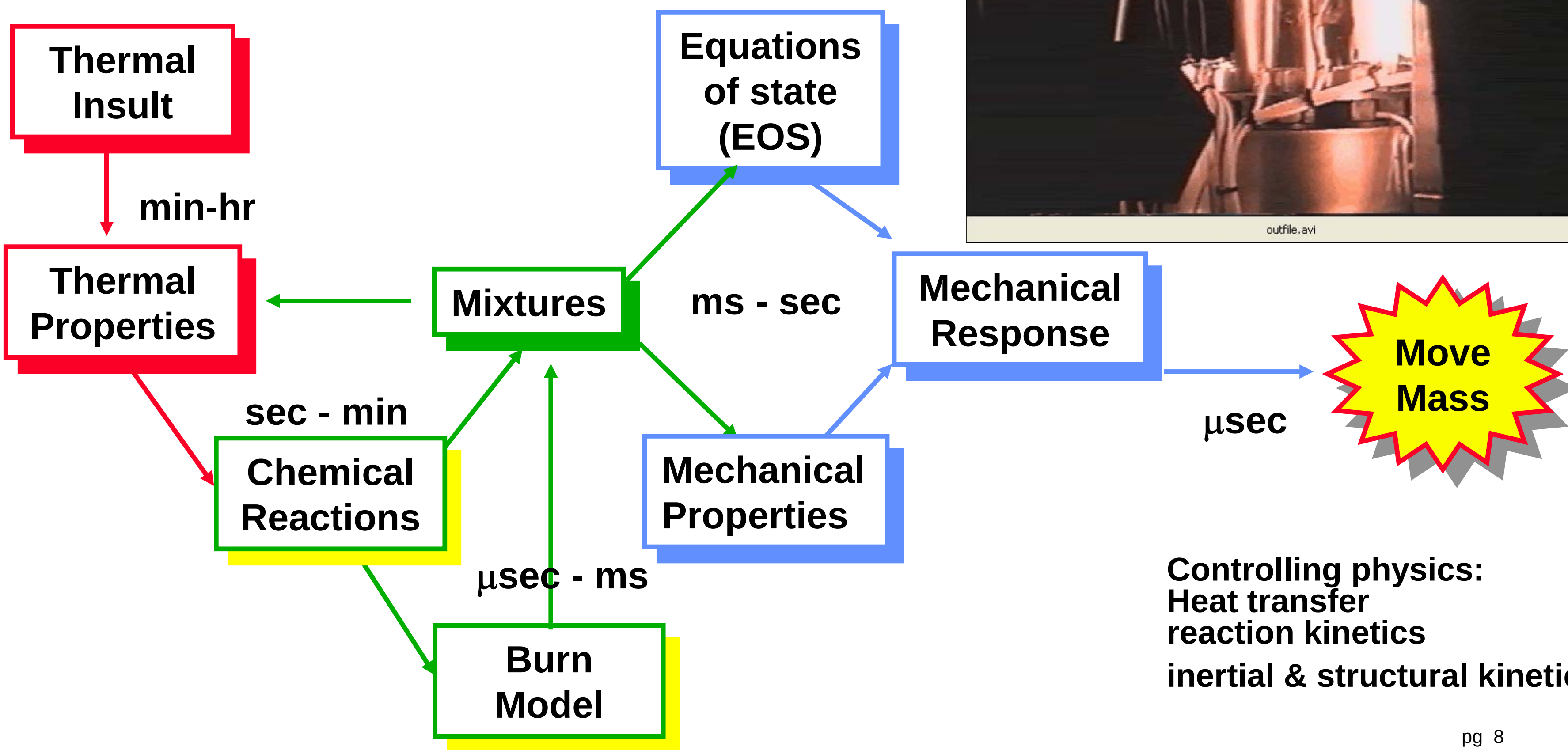
Is this an impossible calculation?

Hard but not impossible

High Explosive (HE) cook-off:
An illustration of a coupled MSMP problem

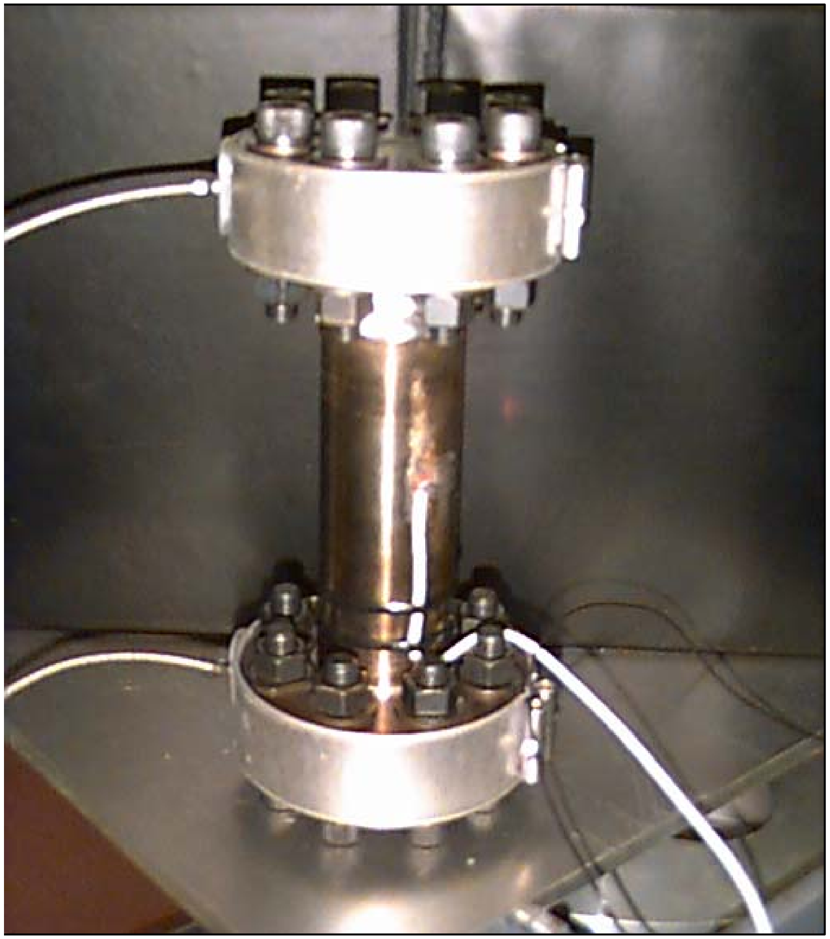
An explosive can be subjected to a fire for a period of many hrs before it reaches conditions necessary for violent disruption to occur.

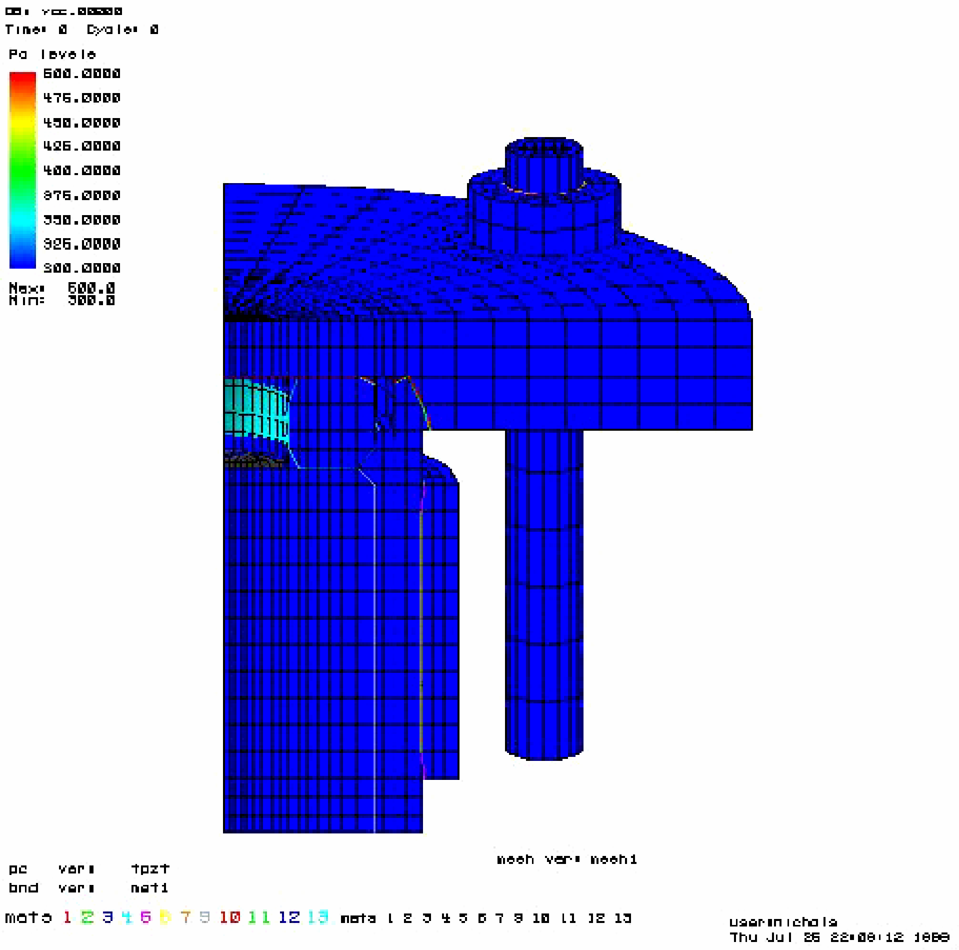




Controlling physics:
Heat transfer
reaction kinetics
inertial & structural kinetics

HE cook-off: Predicting thermal cook off using an MPMS code

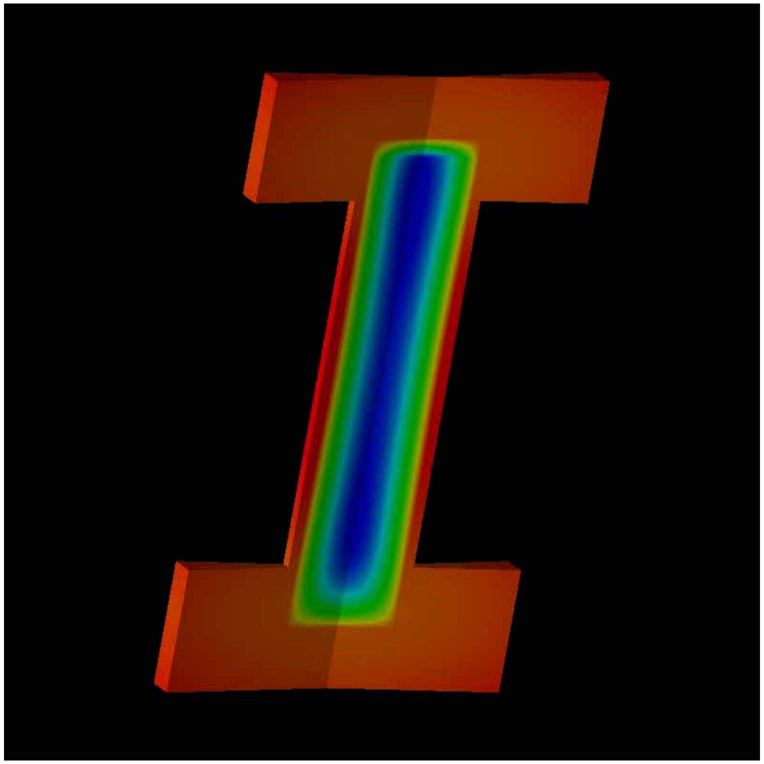




HE cook-off: Predicting thermal cook off using an MPMS code

Temperature prediction

Pressure prediction



Summary

- Presented an extreme MPMS reactor example
- Presented a parallel example that has been solved for a different application
- Majority of the physics needed for the ANS reactor flow blockage problem is represented by the HE cook-off problem.
- Significant MSMP capability already exists at LLNL that can readily be applied to nuclear reactor problems